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To: Mr. D.A. Lee
Manager
Safety Services Department
Health & Safety Division H2 A20

EVALUATION OF IREQ ELECTROMAGNETIC DOSIMETER PERFORMANCE

K.E. Donnelly

The electromagnetic dosimeter developed by IREQ has been evaluated under 16 categories of electronic performance. The dosimeter has high sensitivity, five channel design and data logging capability, and should fill the needs of many studies of occupational exposure to electromagnetic fields. For epidemiology, the time profile of field intensities makes possible the use of different exposure metrics, such as time-weighted average, peak value, or time above a threshold.

While the dosimeter is well designed for use in epidemiological studies of electrical workers, several concerns about its performance exist: 1) loss of sensitivity at low temperatures (-12 C); 2) erratic readings when overloaded; 3) readings in the top bin in occupational situations, leading to ambiguity on maximum fields encountered; 4) requirement to use a Hewlett-Packard computer.

It is recommended that a proposed commercial version of the IREQ dosimeter be conditionally adopted, as it is expected that these concerns will be rectified. Similar performance tests will be necessary before final adoption because of the intended design changes.

BACKGROUND

Exposure assessment is an important component in epidemiological studies of the occupational health effects of 60 Hz electromagnetic fields. It is well recognized that a very wide range of exposures, both in field strengths and in duration, occurs in the electrical trades. It is also well recognized that attempts to estimate such exposures, based on calculated fields and exposure times, are very inaccurate. Acquisition or development of a suitable exposure monitoring device is therefore a prerequisite to a meaningful study.

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At the request of Health and Safety Division, the Science Section of Electrical Research Department undertook to evaluate the performance characteristics of a personal exposure monitor developed by IREQ. This report documents our findings, based on a program of tests which took place in December 1987 and January 1988.

The IREQ dosimeter measures and records three axes of magnetic field data and one axis of electric field data at intervals of approximately five or sixty seconds. Sensitivity of the dosimeter covers a range of 0.6 Volts/metre to 10 Kilovolts/metre and above in electric field, and from to 3 nanoTesla to 50 microTesla and above in magnetic field. Resolution is determined by a structure of sixteen bins, each being a factor of two higher than the previous bin. Recording time is 1.5 or 18 days, depending on the sampling interval chosen. A fifth channel measures electromagnetic disturbances in the 5-20 MHz range. A summary of the manufacturer's specifications is attached for reference.

The dosimeter is provided with an extensive menu-driven software package that controls reading and resetting the dosimeter, storing data in files, viewing time profiles on any of six possible measuring variables, selecting data windows and generating histograms. At present, this package runs on Hewlett-Packard Series 200 and 300 computers, and communication between dosimeter and computer occurs via a custom interface and HP-GPIO board.

Production of the dosimeter on a commercial scale has been licensed to the Montreal electronics firm POSITRON INDUSTRIES. During the course of the evaluation, this investigator and David Agnew of Health and Safety Division visited POSITRON to discuss our findings and learn of planned electronics design modifications.

SCOPE

This evaluation report concerns only the electronic performance of the IREQ dosimeter. Familiarization with software took place during a short preliminary test program; comments at that time were recorded in a memorandum[1]. It was concluded that the software supplied was adequate for dosimeter readout and data viewing, and that any needs not met by the program could be addressed by program modifications or specialized file manipulation routines.

Economic and practical aspects of setting up a dosimetry system based on the IREQ dosimeter, which presently requires a Hewlett-Packard Series 200 or 300 computer and certain mass storage and interface devices, are not addressed in this report.

Acceptability of the dosimeter to wearers, in terms of mass and size, was not evaluated in this study. A single-axis magnetic dosimeter developed by Ontario Hydro Research Division of nearly identical size and mass was used in a previous study[2]; that unit was acceptable, though likely at the tolerable limits, and it was felt that a smaller, lighter unit would enhance wearer cooperation.

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1. K. Donnelly/S. M. Harvey to M. Walsh; Oct 30, 1987.

2. D. Agnew, private communication.

Tests were carried out using free field conditions. Dosimetric aspects of wearing location were not studied.

As there is no intention at present to monitor high frequency disturbances, the electromagnetic channel (5-20 MHz) was not evaluated.

TEST FINDINGS AND CONCLUSIONS

Test results in sixteen categories are given in the Table, "Summary of Findings." Test methods and results are discussed in the Appendix.

Given the high sensitivity, five channel design and data logging capability, the dosimeter should fill the needs of many studies of occupational exposure to electromagnetic fields. For epidemiology, the time profile of field intensities makes possible the use of different exposure metrics, such as time-weighted average, peak value, or time above a threshold.

The dosimeter performs to specifications in most areas tested. However, several areas of concern have been identified.

1. Temperature Range. Sensitivity is decreased by 50% at - 12 C, and more at lower temperatures.

2. Overload Capability. There are indications that the dosimeter may give erratic readings when overloaded.

3. The range of the instrument is 3 nT to >50 uT. A non-negligible fraction of exposures encountered in live-line work will occur in the highest bin[3], resulting in ambiguity in these readings. A shift of the range by the equivalent of two bins would likely be satisfactory to resolve this problem, while retaining sufficient sensitivity at the low end for residential fields. The electric field ranges should also be moved upward by the same amount.

4. The computer used to read the dosimeter and view data is a Hewlett-Packard laboratory instrument. Because of the high cost ($20K - $25K) and specialized nature of this computer, and the availability of IBM compatible portable computers which would be more suitable for field studies, we conclude that IBM-PC versions of the IREQ dosimeter are preferable for use by Ontario Hydro.

These concerns were raised in discussions with technical staff at POSITRON. Their unit will be microprocessor based, unlike the IREQ device, and some redesign of front-end electronics will take place. They had already decided that the unit would be available only with an RS-232 interface for use with IBM-PC compatible computers. They are looking for guidance from the user community on a desirable field range for the instrument.

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3. D. Agnew, private communication.

Succesive bins increase in field by a factor of two. We believe this resolution is adequate for epidemiology studies and for preliminary screening applications. However, much higher resolution (5-10%) would be needed in an instrument used for research purposes, such as the planned study of the sources of residential magnetic fields.

Although the instrument measures three axes of magnetic field, it is not configured to relate their phases and thereby measure the extent of elliptical polarization. This could be a drawback in multiphase situations, or where there are power factor considerations.

COMPARISON TO OTHER UNITS

Two other electromagnetic dosimeters are known to be available for occupational studies. ENERTECH Consultants has developed a microprocessor-based portable electric and magnetic field data logger for EPRI. This unit has similar electronic characteristics to the IREQ device, but is somewhat larger and uses a sash to measure electric fields. In its present form it is less suited to workplace studies where the device must be as non-intrusive as possible. Ontario Hydro Research Division developed a single-axis magnetic exposure monitor for a preliminary workplace study of live-line and switchyard workers. Because of the interpretive difficulties with a single axis, and the need for a separate electric field monitor, this unit cannot provide as thorough an exposure picture or be as convenient for field studies as the IREQ dosimeter.

RECOMMENDATIONS

The specifications of the IREQ dosimeter appear in most respects to meet the needs of the planned study of electrical utility workers' exposure to electric and magnetic fields. Some technical concerns have been identified, including that of range of the instrument, but it is expected that these will be eliminated in the POSITRON version of the dosimeter.

It is recommended that the IREQ dosimeter in its POSITRON version be conditionally adopted for the workplace study. As there will be significant design changes in the production model, it is further recommended that a similar set of tests be carried out before formally adopting this instrument to ensure performance to specifications.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

Keith E. Donnelly*
Physicist
Science Section
Electrical Research Department

* On attachment from Health & Safety Division

SUMMARY OF FINDINGS

	TEST	RESULTS	COMMENTS
1.	Linearity.	Magnetic - within 9%. (Bins 8 - 15) Electric - within 9%. (Bins 9 - 15)	Satisfactory
2.	Low-field Capability.	Magnetic - linear to bin 2. Jitter free to bin 2. Electric - assumed similar.	Satisfactory
3.	Minimum Readings	Magnetic - bins 0,1. Sensitivity .006 uT. Electric - bin 0. Sensitivity .6 v/m.	Satisfactory
4.	Transition Width	< 4 % of field at threshold	Satisfactory
5.	Vector Summation	Thresholds are up to 14% low, depending on orientation.	Satisfactory for dosimetry application with 2:1 bin thresholds.
6.	Isotropy of magnetic response.	Axes agree within 4 $\pm$ 3 %.	Satisfactory No capability to measure elliptical polarization.
7.	Comparison to calibration.	Magnetic: 7.3% difference. Electric: 0.4% difference.	Satisfactory.
8.	Dynamic Range.	Magnetic: .003 uT - >50 uT. Electric: .6 V/m - >10KV/m.	Satisfactory for residences, many industries. Questionable for electric utility workers.
9.	Bin Width	Fields increase 2x per bin.	Satisfactory for dosimetry. Insufficient resolution for research.

10.	Frequency Dependence.	Magnetic: Flat, 60 Hz - 2 KHz. Sharp fall below 60 Hz.	Responds to magnetic harmonics, but not electric.
		Electric: Falls at 3 bins per decade above 60 Hz. Sharp fall below 60 Hz.	If detector is peak sensing, effect of harmonic distortion is not clear.
11.	Temperature Dependence	No sensitivity change +4 - +40 C.	May result in questionable data if used at winter temperatures.
		1/2 bin loss of sensitivity (50%) at - 12 C.	Satisfactory for use at summer temperatures up to 40 C.
		1 bin loss of sensitivity (100%) at - 25 C.	
12.	Overload Capability.	Large overloads cause alternation between bins 14, 15. Behaviour of other channels may be affected adversely. Overloads may damage bin 15 capability.	Of concern. High fields may occur inadvertently or deliberately.
13.	Timing Constancy.	Sampling interval changes by up to 6%. No obvious cause.	May cause difficulty in relating events to changes in fields.
			Differs from unit to unit.
14.	Battery Drain.	As specified during data acquisition. (1.1 - 1.4 mAmp.)	18 day operation is marginal, at best
		Standby mode did not become operative when expected (150 uAmp).	Data may be lost if not readout promptly.
15.	Battery Voltage.	Thresholds change by < 4% for expected changes of battery voltage.	Satisfactory
16.	Crosstalk.	No crosstalk observed between E, M measurements.	Satisfactory

Characteristics and Features

* Weight is 218 g, without battery.

* Dimensions are 2.3 x 8 x 14.3 cm.

* Power source is a 9 V transistor battery; industrial alkaline recommended.

* Autonomy, memory limited, is 18 days (1.5 days for TURBO setting).

* Measures 3 variables: Electric Field (50 or 60 Hz), Magnetic Field (50 or 60 Hz), ElectroMagnetic Disturbances (5-20 MHz).

* Tri-Axial Magnetic Measurements (X,Y,Z).

* 84 dB Dynamic Range on all 3 variables.

* Complete History Stored (64 kbytes x 8 memory inside the unit).

* Automatic Shut-Off with long term Data Preservation.

* Exactly Logarithmic Bin Scales.

* Measurements each minute or each 5 seconds in the TURBO setting.

* Data Output to series 200-300 Hewlett-Packard micro-computer (GPIO card).

* Software provided for data display and evaluation.

* Temperature range (unit autonomy may be affected): -25 deg C to 60 deg C.

BIN CLASSIFICATION SCHEME

BIN	ELECTRIC (V/m) (FREE)	MAGNETIC (μT)	ELECTROMAGNETIC (20 MHz CLOCK)
0	0.00-0.61	0.00-0.0031	0.00-0.8 ppb
1	0.61-1.22	0.0031-0.0061	0.8-3.3 ppb
2	1.22-2.44	0.0061-0.0122	3.3-13.3 ppb
3	2.44-4.88	0.0122-0.024	13.3-53 ppb
4	4.88-9.77	0.024-0.049	53-220 ppb
5	9.77-20	0.049-0.10	220-850 ppb
6	20-39	0.10-0.20	850-3330 ppb
7	39-78	0.20-0.39	3.33-13.7 ppm
8	78-156	0.39-0.78	13.7-55 ppm
9	156-312	0.78-1.56	55-218 ppm
10	312-625	1.56-3.13	218-873 ppm
11	625-1250	3.13-6.25	873-3500 ppm
12	1250-2500	6.25-12.5	3500-13983 ppm
13	2500-5000	12.5-25	13983-55917 ppm
14	5000-10000	25-50	55917-223700 ppm
15	10000>——	50>——	223700>——ppm

APPENDIX

DISCUSSION OF METHODS AND FINDINGS

A. Linearity and Related Characteristics

1. Linearity

In the case of an instrument with a logarithmic bin structure, linearity refers to an assumed straight-line relation between bin identification number and the logarithm of bin thresholds.

Magnetic field bin thresholds were measured for bins 7 - 15[4] to a resolution of ± 9%; the resulting calibration curve is shown in Figure 1. Only the Y-axis was used, as identical preamplifiers are multiplexed into a single digitizing circuit. A comparison of gain on the three individual axes is made in section 6 below. In this range of bins, thresholds are logarithmic within the measurement uncertainty. Two adjacent bin boundaries were measured in a separate measurement to a resolution of ± 2%; within the experimental uncertainty, they were exactly in the ratio 2:1 as designed.

Magnetic fields for this test were generated in a 1 metre diameter Helmholtz coil pair, with a field calibration factor known to better than 2%. Fields were calculated from the current, measured by a digital current meter (Beckman Model RMS 3030) in conjunction with an accurately calibrated analog current meter (Weston Model 155).

Electric field bin thresholds were measured for bins 8 - 15, also to a resolution of ± 9%; see Figure 2. These are exactly logarithmic within the measurement uncertainty.

Electric fields were generated for this test by a set of parallel plates of dimensions 30x30 cm, separated by 15 cm. The dosimeter was placed on the mid-plane, supported by a block of low-density styrofoam. Fields were corrected for the separation of the dosimeter plates, as they are effectively shorted by the current measuring amplifier. Voltages were supplied from an autotransformer driven high-voltage coil capable of 15 KV at 120 V primary excitation, and measured by a Hewlett-Packard Model 3411A high-voltage probe and Fluke Model 77 digital voltmeter calibrated to 1%. This measuring setup was also calibrated by comparison to an electrostatic voltmeter of known accuracy. This electric field apparatus was supplied and operated by Safety Devices Section of Health and Safety Division at its McKay Road, Pickering facility.

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4. Bins will be denoted 0 - 15, with bin 15 having the highest field values.

Each threshold was determined from a sequence of 60 second exposures. In TURBO mode, this gave 12 samples at each field level, sufficient to observe statistical fluctuations and giving a readout display from which response could easily be correlated with exposure (see, for example, Figure 4 below). Exposures in each sequence increased in a geometric progression with factors of $2^{1/4}$, $2^{1/8}$ or $2^{1/16}$, depending on the resolution required.

2. Low Field Capability

Because of its high sensitivity, the dosimeter measures normal laboratory background fields in its middle bins. For this reason, the above linearity tests could not be extended directly to lower ranges.

To observe the behaviour of the device in its lower bins, magnetic exposures were carried out in a small magnetically shielded enclosure. The shielding arrangement consists of two concentric iron pipes, as described in the next section. By wrapping a single turn of wire around the dosimeter, it was possible to create the required magnetic fields with milliampere currents. The current to effective-field factor was determined from a calibrated bin threshold at higher field.

The linearity was checked down to bin 2 (.006 uT) on the magnetic Y-axis; the curve is shown in Figure 3. Thresholds are exactly logarithmic to within the measurement uncertainty, ± 9%.

It is worth noting that magnetic readings are noise-free (no jitter between bins) in mid-bin down to bin 2, and sharp transitions between bins are also maintained to bin 2. These factors allow the observation of true fluctuations in background fields in workplace or residential environments.

At fields below the bin 2 threshold, readings are in bins 0 or 1 and cannot be distinguished from the normal zero-field behaviour.

Electric fields at lower than bin 8 were not observed for linearity; however it is expected that the behaviour will be identical or superior to the magnetic sensing circuits. A common digitization circuit is employed, and moreover, the electric field transducer and preamplifier were observed to be noise-free (bin 0 response without jitter) at zero field created in an electrostatic shield.

3. Minimum Readings

To ascertain the minimum possible readings of the instrument, shielding was used to create environments as near to zero electric or magnetic field as possible.

For electric fields, shielding was achieved by wrapping copper foil around the dosimeter. This resulted in readings in bin 0, with no jitter. No further attempt was made to estimate the residual field.

For magnetic fields, a shielding enclosure was assembled from two iron pipes (11.4 cm O.D. x30cm length x .79 cm wall; 15.9 cm O.D. x 27 cm length x .64 cm wall) arranged concentrically. The shielding factor for the inner pipe alone, perpendicular to the pipe axis, is 90 $\pm$ 14%. This was determined using a Hall effect gaussmeter to measure fields in the 1 metre Helmholtz coil pair.

When placed in this magnetic shield, the dosimeter reads in bins 0 and 1 ; see Figure 4. This appears to be the minimum possible reading. Although it is not possible to ascertain the true fields within the shield, they are believed to be well below the bin 1 threshold. This conclusion is based on the known background fields and measured shielding factor, and on the lack of difference between single and double shield conditions.

4. Transition Width

The transition between magnetic bins 11 and 12 was observed to occur within a field variation of 4% or less. This defines the interval in which a reading at a given field may fall in either of the adjacent bins; within the bins proper, no jitter is observed. Figure 5 illustrates this definition.

5. Vector Summation

The three magnetic field components are added vectorially by the software following readout, rather than electronically in real time. This reduces the need for an additional data storage channel in the device. Because the vectorial combinations of bin boundaries do not correspond exactly to boundaries of higher bins, this mathematical procedure introduces a shift in the effective bin threshold, which is dependent on the field orientation.

In the software, an assumption is made that each reading occurs at the mid-point of its bin[5]. The vector addition is carried out from a lookup table for each combination of three bins. The resultant is then allocated to the bin in which it falls.

An experimental demonstration of this process was carried out. Using a jig to hold the dosimeter with all axes at equal angles to the field, a composite bin threshold was determined and compared to single axis thresholds. The composite threshold was at 84 $\pm$ 5 % of the single axis threshold, in agreement with the expected value of 86.6 %.

With bin thresholds increasing by a factor of two, this uncertainty is judged to be acceptable for dosimetry and epidemiology.

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5. Louis Richard, IREQ. Private communication.

6. Comparison of Axes

The magnetic bin 12 thresholds for all three axes were measured with a relative accuracy of $\pm$ 2.2 %. The observed difference between axes is 4 $\pm$ 3 %; this difference is not significant in comparison to bin widths.

Relative phases of signals on the three axes are not measured, hence linearly polarized fields cannot be distinguished from elliptical with this instrument. In some field measurement applications around multiphase current networks this may be of concern, but is not likely to be a problem for the present epidemiological study.

7. Comparison to Calibration

Tables 1 and 2 compare the measured electric and magnetic bin thresholds with the calibration figures provided by IREQ for this dosimeter. The average difference for bins which can be compared is 7.3% for magnetic bins and 0.4% for electric bins.

8. Dynamic Range

The dosimeter is designed to cover an 84 db range in both magnetic and electric fields; specifically from 3 nanoTesla to > 50 microTesla and from 0.6 V/m to > 10 KV/m. These ranges are chosen to include ambient fields in both residential and occupational settings.

Recent studies by Agnew et al[6] of Ontario Hydro Safety Services Department have shown exposures of live-line workers extending roughly four times higher than the uppermost bin thresholds in both electric and magnetic fields.

Serious consideration should be given to shifting all electric and magnetic bins upwards by the equivalent of two bins. This would allow the higher occupational exposures to be measured while continuing to include residential fields within the range of the instrument, though in the very low bins.

9. Bin Width

The dosimeter has a logarithmic response, with successive bins increasing in field by a factor of two. This approach allows a large dynamic range to be covered while reducing data storage requirements. The 16-bin structure allows use of a 4-bit "nibble" for data coding.

This bin width is likely adequate for epidemiological uses of the dosimeter. However, for research purposes, such as identifying the sources of magnetic fields or determining their evolution in time throughout a given period, an instrument with higher resolution would be required, on the order of 5-10%.

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6. D. Agnew, private communication.

B. Frequency Dependence

10. Frequency Dependence of Response

The dosimeter response to electric and magnetic fields over a range of frequencies is shown in Figures 6 and 7. These show the response to a fixed field value, rather than bin thresholds. The fields were set for mid-bin response at 60 Hz. A sensitivity curve can be inferred from bin ranges, or from frequencies where response changes from one bin to the next.

Electric field response falls at approximately 3 bins per frequency decade above 60 Hz. Magnetic field response is flat to approximately 2 KHz. Both fall sharply below 60 Hz, and are down one bin at 50 Hz.

From the manufacturer's description, it was not expected that response would be reduced at 50 Hz. Magnetic thresholds were measured with an uncertainty of $\pm$ 9% and the ratio of bin thresholds is

$$B(50\ Hz)/B(60\ Hz) = 1.82 \pm .24$$

The dosimeter senses peak values of alternating half-cycles of the fields; it is not clear how the result is affected if harmonic distortion creates a non-symmetrical waveform. However, this method is unlikely to create a serious error with this bin width for moderate harmonic content.

C. Other Characteristics

11. Temperature Dependence

As it is contemplated that the dosimeter may be used out-of-doors and in most Ontario weather conditions, tests were undertaken to determine the temperature dependence of its performance. These were carried out in a small environmental chamber of inside dimensions 60x60x60 cm.

Magnetic bin thresholds were measured with a 49 cm diameter Helmholtz coil pair centred in the environmental chamber. Electric field exposures were generated with a small set of parallel plates 14x18 cm in area and separated by 10 cm. The need for absolute calibrations was eliminated by using room temperature runs in the chamber as reference.

Bin threshold curves at various temperatures between - 25 C and + 60 C are shown in Figures 8-10. Temperature dependence of specified bin thresholds are shown in Figures 11 and 12.

Linearity of the dosimeter is unaffected for temperatures between - 25 C and + 40 C. That is, bin boundaries remain separated by a factor of exactly 2.

No change of sensitivity of the device is noted within experimental uncertainty for the temperature range + 4 C to + 40 C. However the following changes are observed outside that range:

Approximately 50% loss of sensitivity (1/2 bin) at - 12 C

Approximately 100% loss of sensitivity (1 bin) at - 25 C

Approximately 400% loss of sensitivity (2 bins) at + 60 C
(measured for magnetic fields only).

12. Overload Capability

Response of the device to fields up to ten times higher than the highest bin threshold was studied, as this situation may be encountered inadvertently or through deliberate misuse. Desirable performance would consist of a reading in the highest bin (bin 15) and absence of permanent change or damage to the device.

Test results in this category were not reproducible, but overload exposures in most cases produced readings which either occur in lower bins (bin 14) or alternate between bins 14 and 15.

Due to the methods used to generate high fields, it was not possible to control all parameters during the tests. This will account for some inconsistencies between tests which are not explainable without an understanding of the circuit behaviour under overload. As an example, high magnetic fields in one test were generated with a coil wrapped directly around the dosimeter case; this produces a non-uniform field which couples to all three field coils. When the first magnetic axis overloads, readings on the other two axes fall by three bins, even though below overload by at least three bins. This is shown in the tracings of Figure 13.

Electric field overloads were generated both in the 15 cm separation chamber using high voltage excitation, and using insulated plates attached to the dosimeter case, driven by low voltage. Both situations resulted in readings in bin 14 (fields above 70 KV/m), or alternating between bins 14 and 15.

After overload tests were conducted, sensitivity in lower bins was unchanged from previous values and zero field readings were as described above in section 3. However it appeared that the threshold for overload had been lowered and it was no longer possible to achieve a normal bin 15 reading.

All overload tests were carried out in the 5-second sampling interval mode. Since sample acquisition time depends on field amplitude (some form of successive-approximation analog-to-digital conversion is used), it is not clear if the time available for sample conversion bears on this behaviour.

13. Timing Constancy

Sample interval timing is determined by passive circuit elements and varies from dosimeter to dosimeter. Using the known time interval between events separated by several hours, the sampling period may be determined from the time profile generated by the software. Variations in period of up to 6% were observed. No cause, such as changes in battery voltage, was ascertained for these variations. Temperature dependence has not been ruled out as a cause, as changes of period were observed during environmental tests but could not be confirmed over long enough time intervals. It is possible that it may depend on signal levels, as these determine sample acquisition time.

In some types of study, it may be important to correlate changes in field with job events, which could only be done with a reasonably accurate time base.

14. Battery Drain

Supply current from the 9-volt battery was measured during several phases of operation and agreed with the specified values of 1.1 mAmp following dosimeter reset and 1.4 mAmp following triggering. (TURBO mode, 5 sec intervals). An operating current of 1.4 mAmp was also measured in the NORMAL mode, (60 sec intervals).

In TURBO mode, the dosimeter was not observed to go into a standby mode, in which current drain is around 150 uAmp. This was expected to occur following battery installation and following readout. It should also occur when supply voltage falls below 6.3 volts, but a change was not observed until the supply has been reduced to 1.4 volts. However, standby mode following battery insertion was observed in NORMAL mode.

From curves supplied by the battery manufacturers[7], we estimate the service capacity for a 9 V alkaline battery (discharged at this rate to 6.3 V cutoff) to be 430-460 mAmp hrs. This converts to an operating time of 12.9 days, in contrast to the quoted recording time of 18 days. Our tests were not performed in a manner to observe a full 18 days operation on one battery, so we are dependent on this theoretical comparison. However, equivalent lithium batteries are available with a capacity of 1100 mAmp hrs if battery life proves problematical.[8]

15. Battery Voltage

A magnetic bin threshold was measured for a range of supply voltages. Changes of 4% or less were observed over the range 7.0 - 9.3 volts. Figure 12.

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7. "EVEREADY" Type 522. Eveready Battery Enginering Data, Vol. II, 1982. Union Carbide Corp.

8. SAFT Batteries, Montreal. Type LS 622

16. Crosstalk between Modes

To measure possible crosstalk between electric and magnetic modes, several tests were carried out using shielded enclosures to guarantee zero physical fields in the mode being tested. An exposure to a bin 12 magnetic field (three-axes simultaneously excited) was carried out with copper foil enclosing the dosimeter to exclude externally generated electric fields from the dosimeter. The electric field reading during the magnetic exposure was zero. An electric field exposure at the level of bin 12, using contacting insulated field plates, was carried out inside the magnetic shield described above. Magnetic readings were in bins 0 and 1, consistent with zero field exposure. We conclude that there is no crosstalk between measurement modes.

TABLE 1 - CALIBRATION OF DOSIMETER BINS

ELECTRIC FIELDS

Bin #	Nominal Threshold (volts/metre)	These Tests	IREQ Calibration
0	0.00	-	-
1	0.61	-	.51
2	1.22	-	1.24
3	2.44	-	2.33
4	4.88	-	5.3
5	9.77	-	10.4
6	20	-	20.95
7	39	-	48.5
8	78	-	73.9
9	156	151	155
10	312	360	327
11	625	604	650
12	1250	1210	-
13	2500	2420	-
14	5000	4840	-
15	10000	11500	-

TABLE 2 - CALIBRATION OF DOSIMETER BINS

MAGNETIC FIELDS

Bin #	Nominal Threshold (microTesla)	These Tests	IREQ Calibration X-axis	IREQ Calibration Y-axis	IREQ Calibration Z-axis
0	0.00	-	-	-	-
1	.0031	-	-	-	-
2	.0061	.0075*	-	-	-
3	.0122	.0150*	-	-	-
4	.024	.0327*	.028	.028	.025
5	.049	.060*	.057	.057	.050
6	.10	-	.113	.107	.107
7	.20	-	.276	.264	.251
8	.39	.478	.427	.408	.408
9	.78	.873*	.867	.829	.829
10	1.56	1.75	1.571	1.508	1.445
11	3.13	3.50	3.08	2.95	2.95
12	6.25	6.99	6.91	6.79	6.79
13	12.5	14.0	14.5	13.8	13.8
14	25	25.8	27.6	26.4	26.4
15	50	61.2	-	-	-

* Note: Bins 2-5 are calibrated against bin 9.

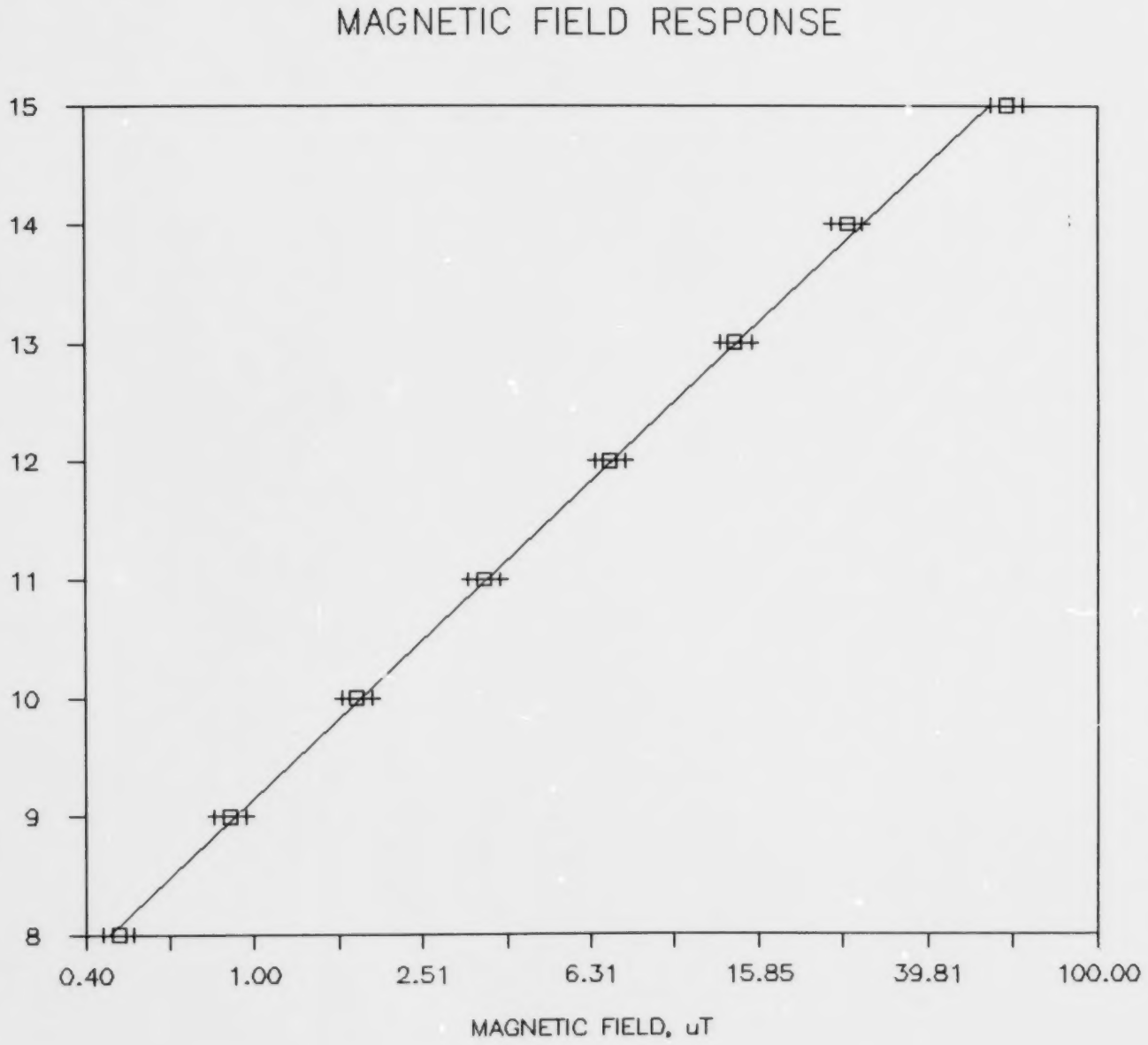

MAGNETIC FIELD RESPONSE
RESPONSE, BIN #
15
14
13
12
11
10
9
8
0.40
1.00
2.51
6.31
15.85
39.81
100.00
MAGNETIC FIELD, uT

FIGURE 1

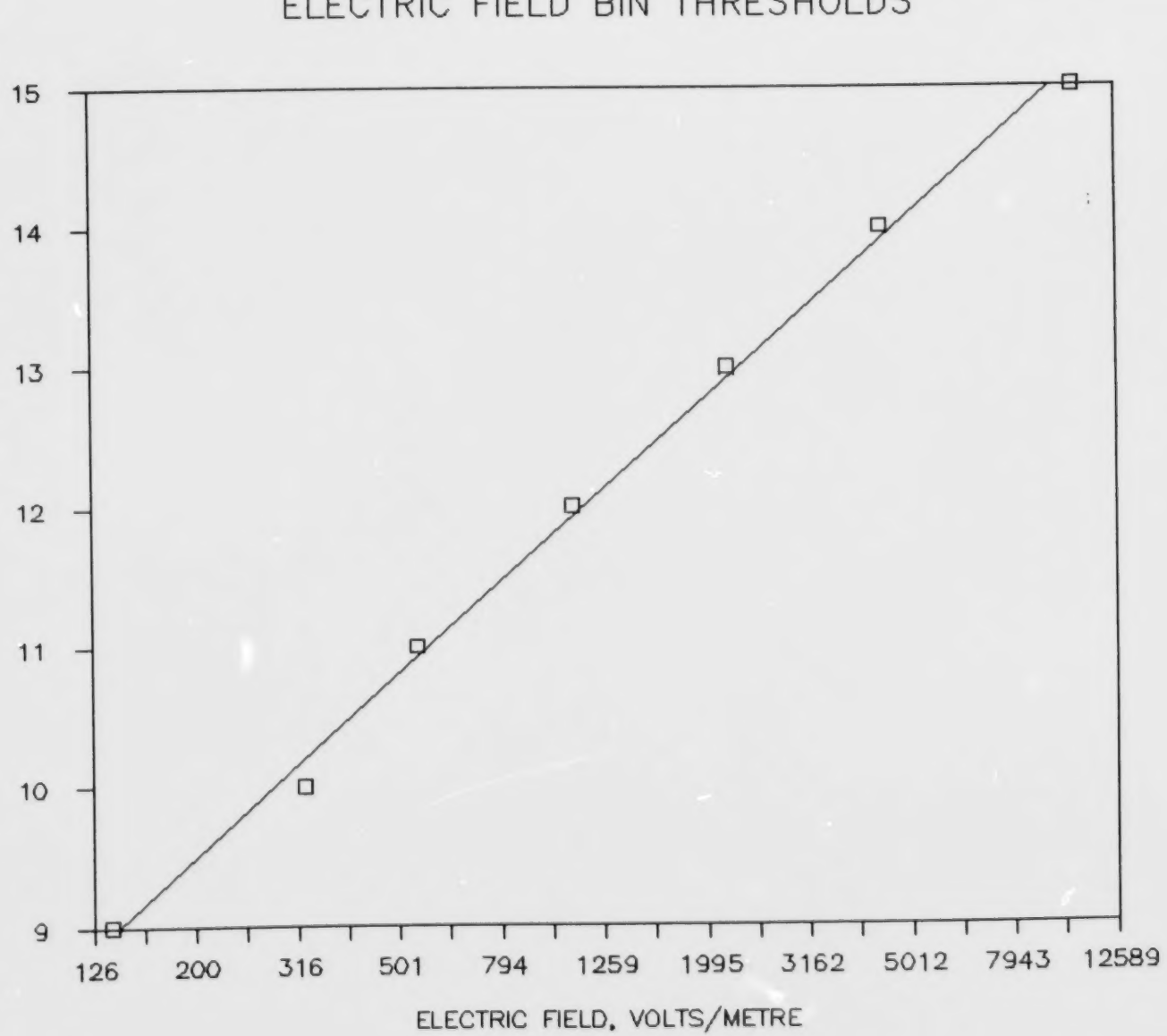

ELECTRIC FIELD BIN THRESHOLDS
BIN #
15
14
13
12
11
10
9
126
200
316
501
794
1259
1995
3162
5012
7943
12589
ELECTRIC FIELD, VOLTS/METRE

FIGURE 2

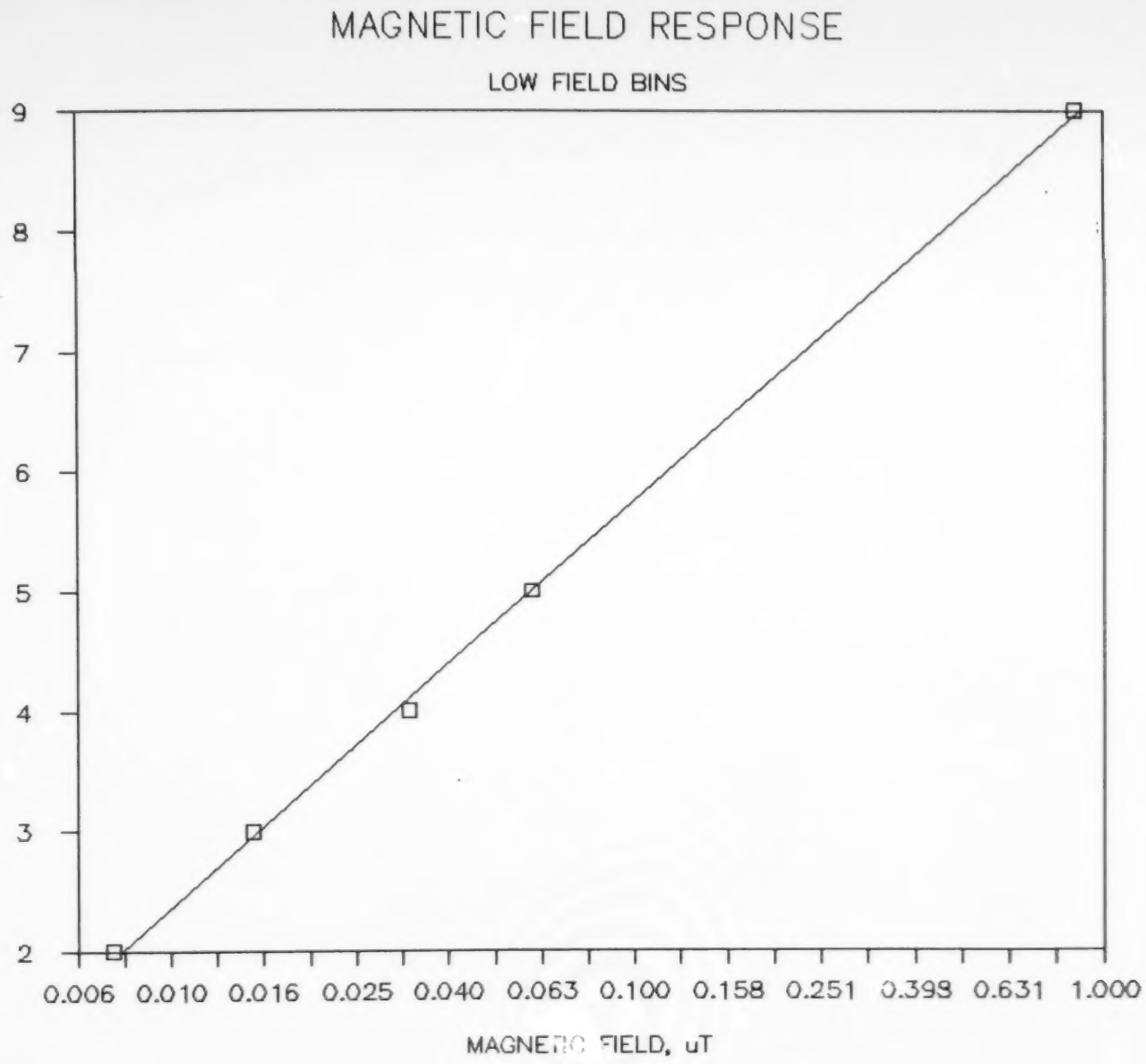

MAGNETIC FIELD RESPONSE
LOW FIELD BINS
9
8
7
6
5
4
3
2
0.006 0.010 0.016 0.025 0.040 0.063 0.100 0.158 0.251 0.398 0.631 1.000
MAGNETIC FIELD, uT

FIGURE 3

User : DBLSHIELD.
Ser.Number :

File : TRI9
Period : 5.02 sec.

START: 31 DEC 1987 , 10:56
Enh. Factor : 1

MAGNETIC FIELD (Y)

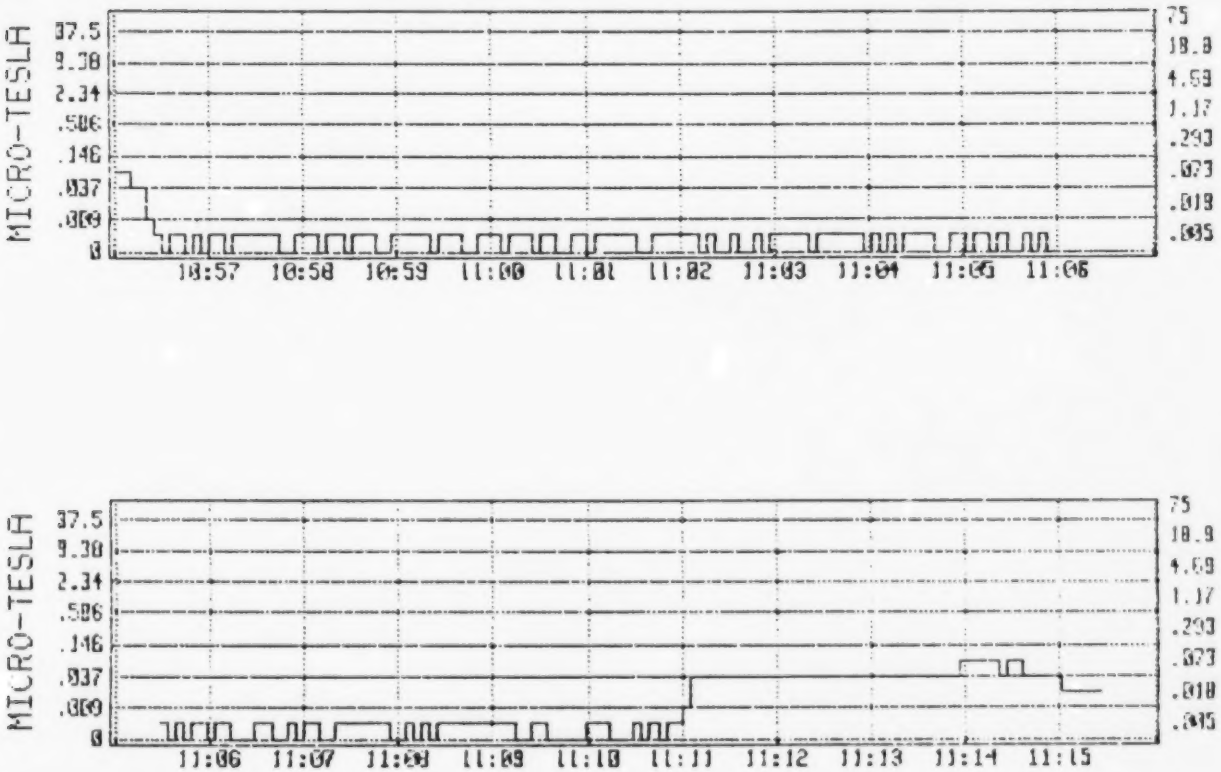


FIGURE 4

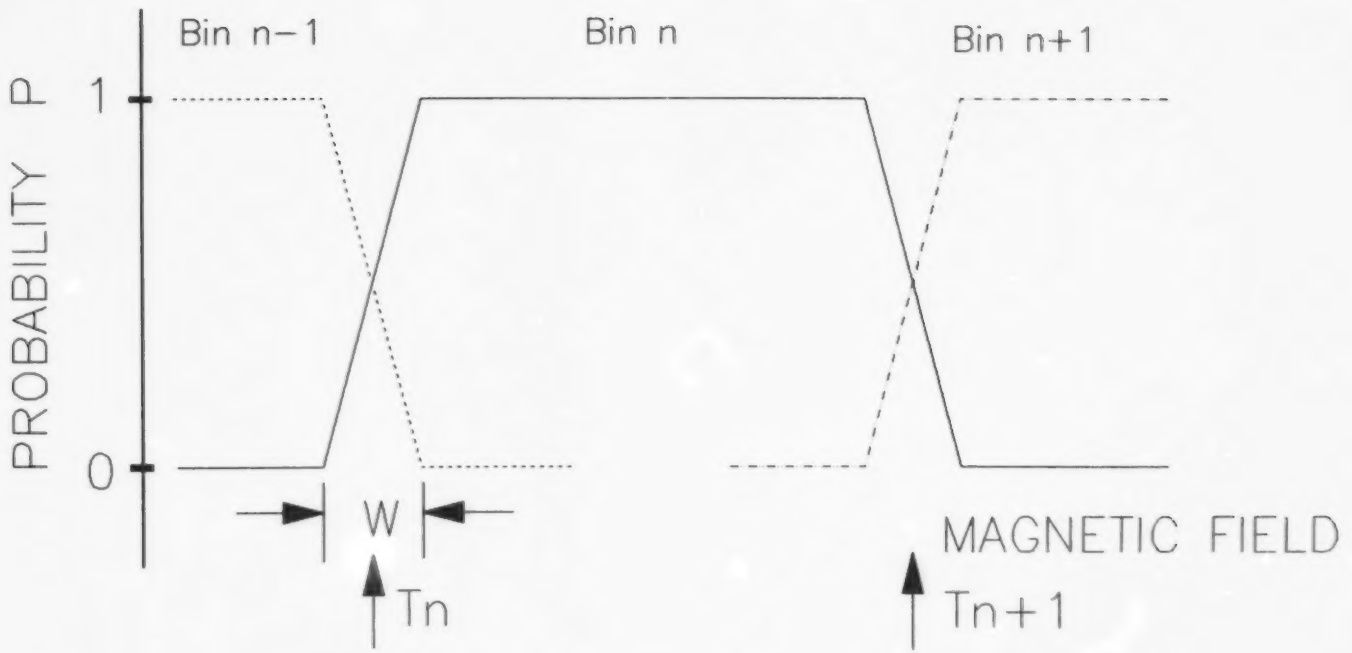


Figure 5. Bin thresholds Tn, Tn+1 and transition width W.
P is probability that reading is in specified bin.

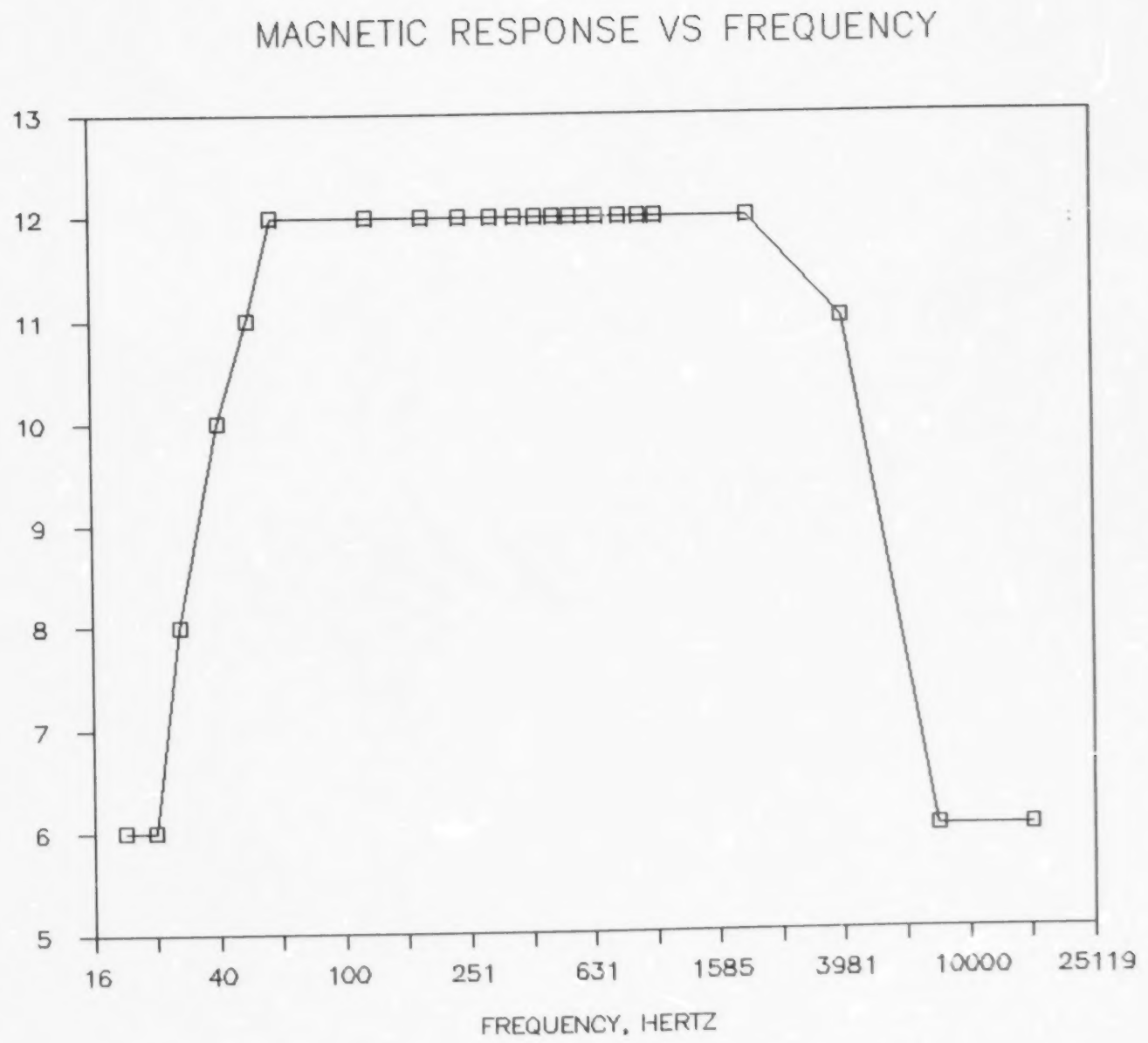

MAGNETIC RESPONSE VS FREQUENCY
13
12
11
10
9
8
7
6
5
16
40
100
251
631
1585
3981
10000
25119
FREQUENCY, HERTZ

FIGURE 6

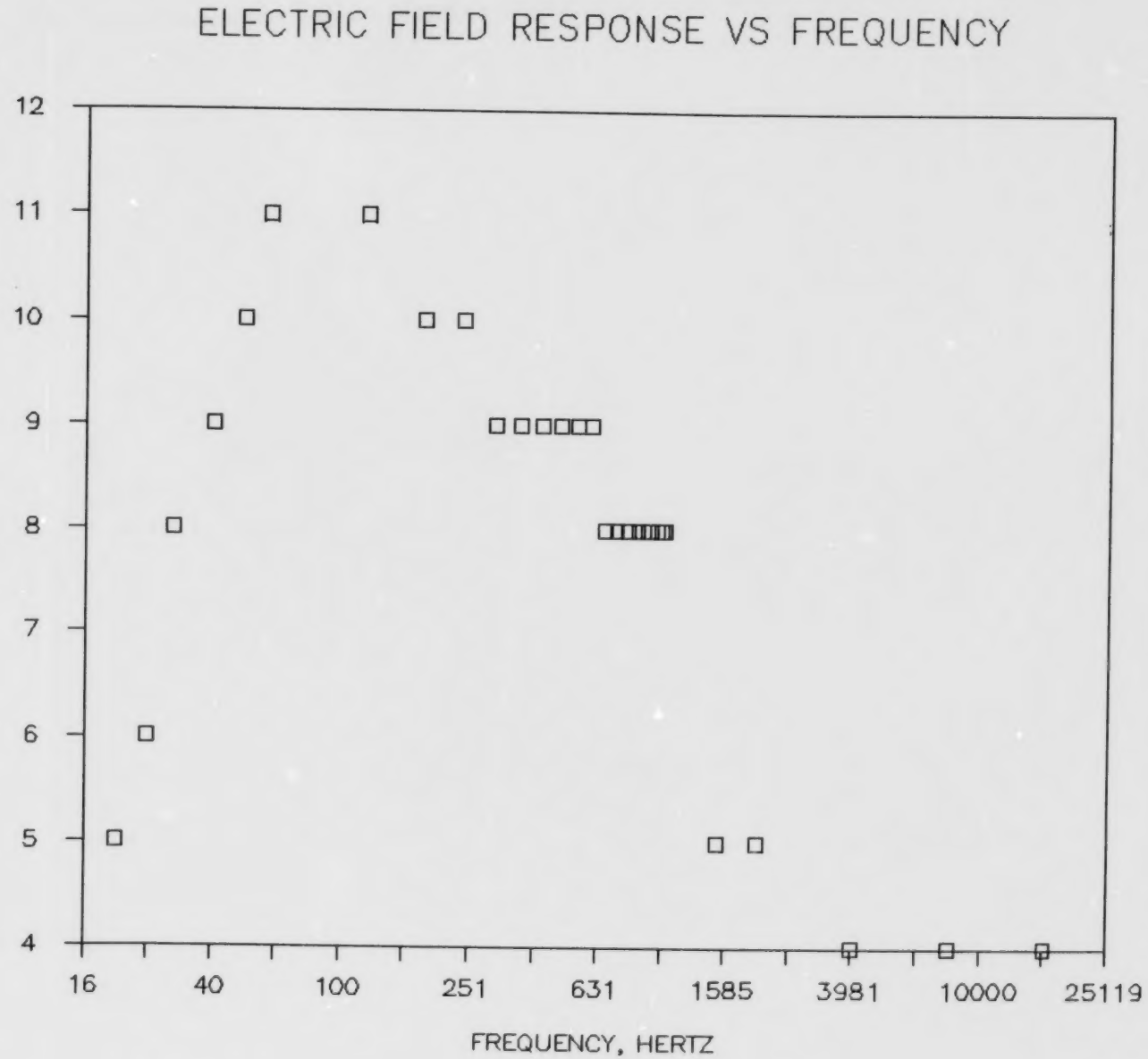

ELECTRIC FIELD RESPONSE VS FREQUENCY
RESPONSE, BIN #
12
11
10
9
8
7
6
5
4
16
40
100
251
631
1585
3981
10000
25119
FREQUENCY, HERTZ

FIGURE 7

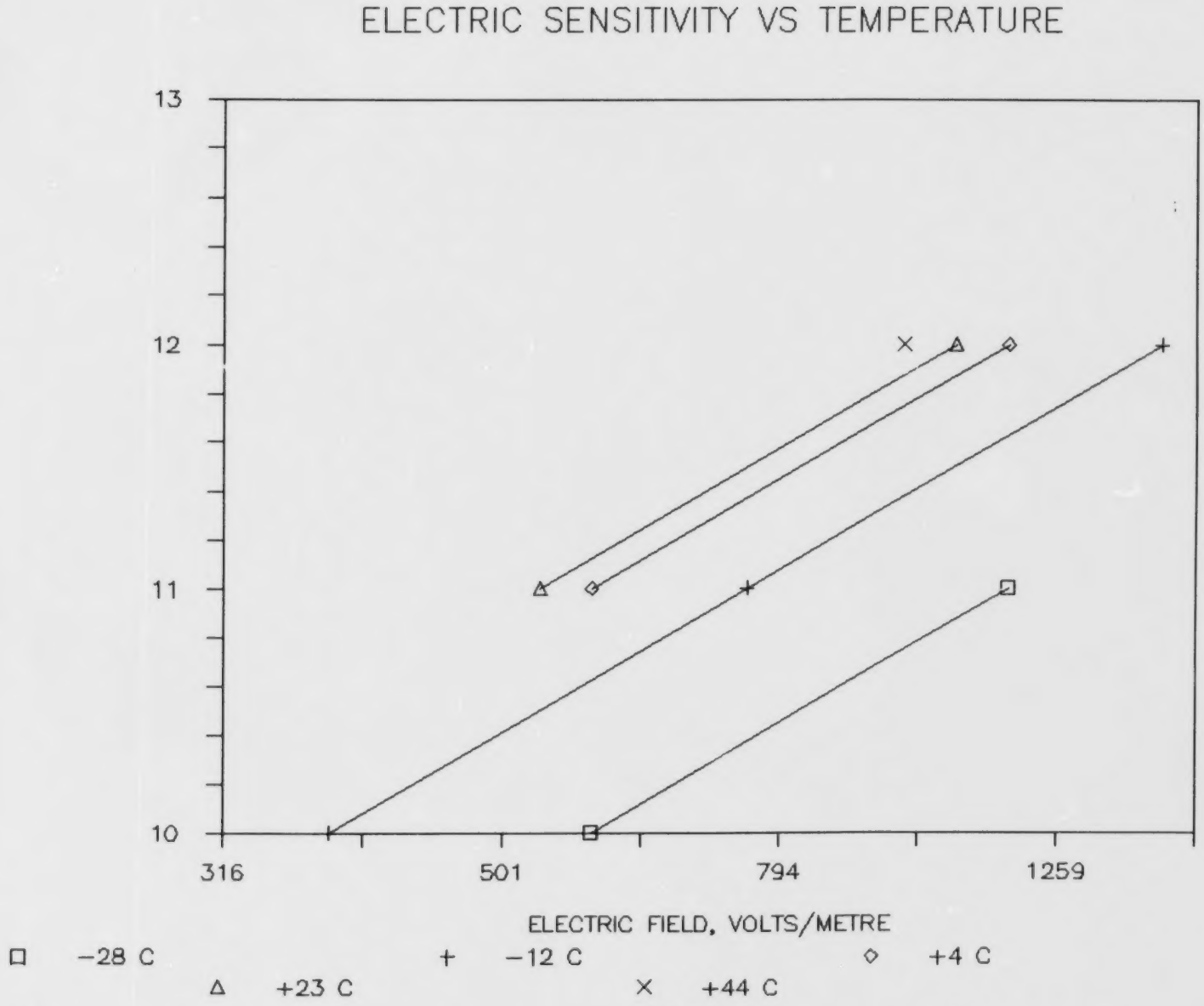

ELECTRIC SENSITIVITY VS TEMPERATURE
BIN #
13
12
11
10
316
501
794
1259
ELECTRIC FIELD, VOLTS/METRE
□ −28 C
+ −12 C
◇ +4 C
△ +23 C
× +44 C

FIGURE 8

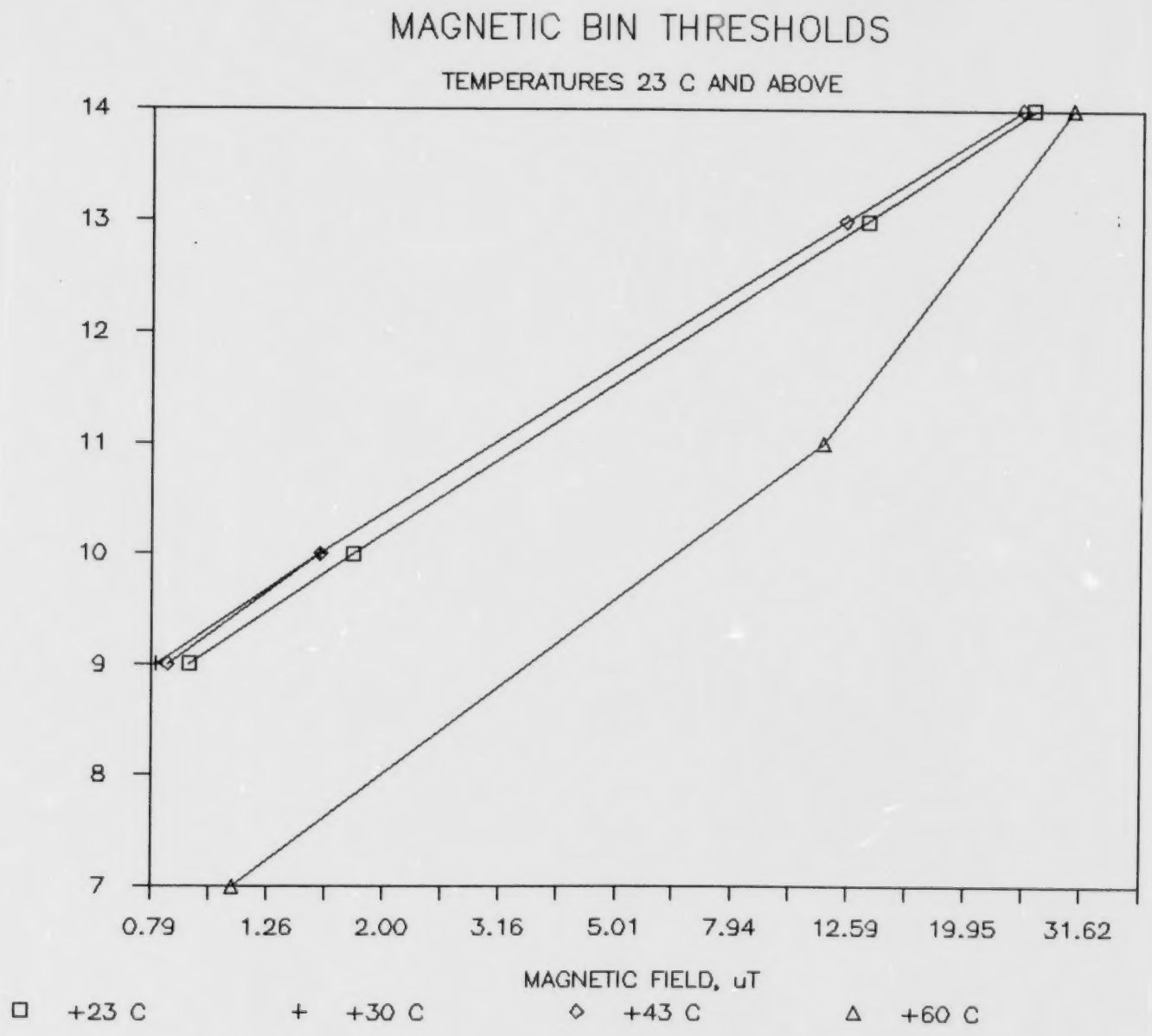

MAGNETIC BIN THRESHOLDS
TEMPERATURES 23 C AND ABOVE
BIN #
14
13
12
11
10
9
8
7
0.79
1.26
2.00
3.16
5.01
7.94
12.59
19.95
31.62
MAGNETIC FIELD, uT
+23 C
+30 C
+43 C
+60 C

FIGURE 9

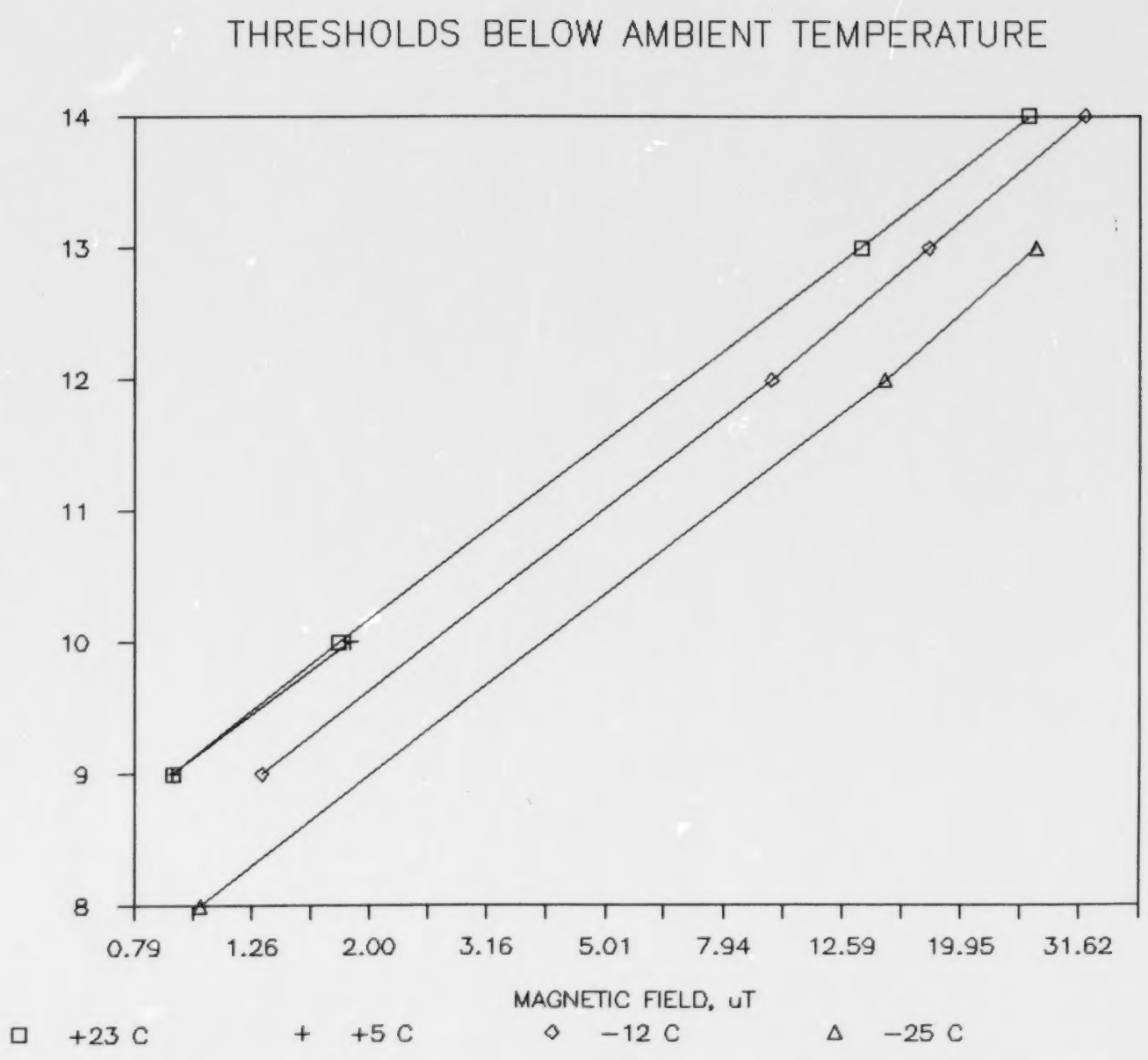

THRESHOLDS BELOW AMBIENT TEMPERATURE
14
13
12
11
10
9
8
BIN #
0.79
1.26
2.00
3.16
5.01
7.94
12.59
19.95
31.62
MAGNETIC FIELD, uT
□ +23 C
+ +5 C
◇ −12 C
△ −25 C

FIGURE 10

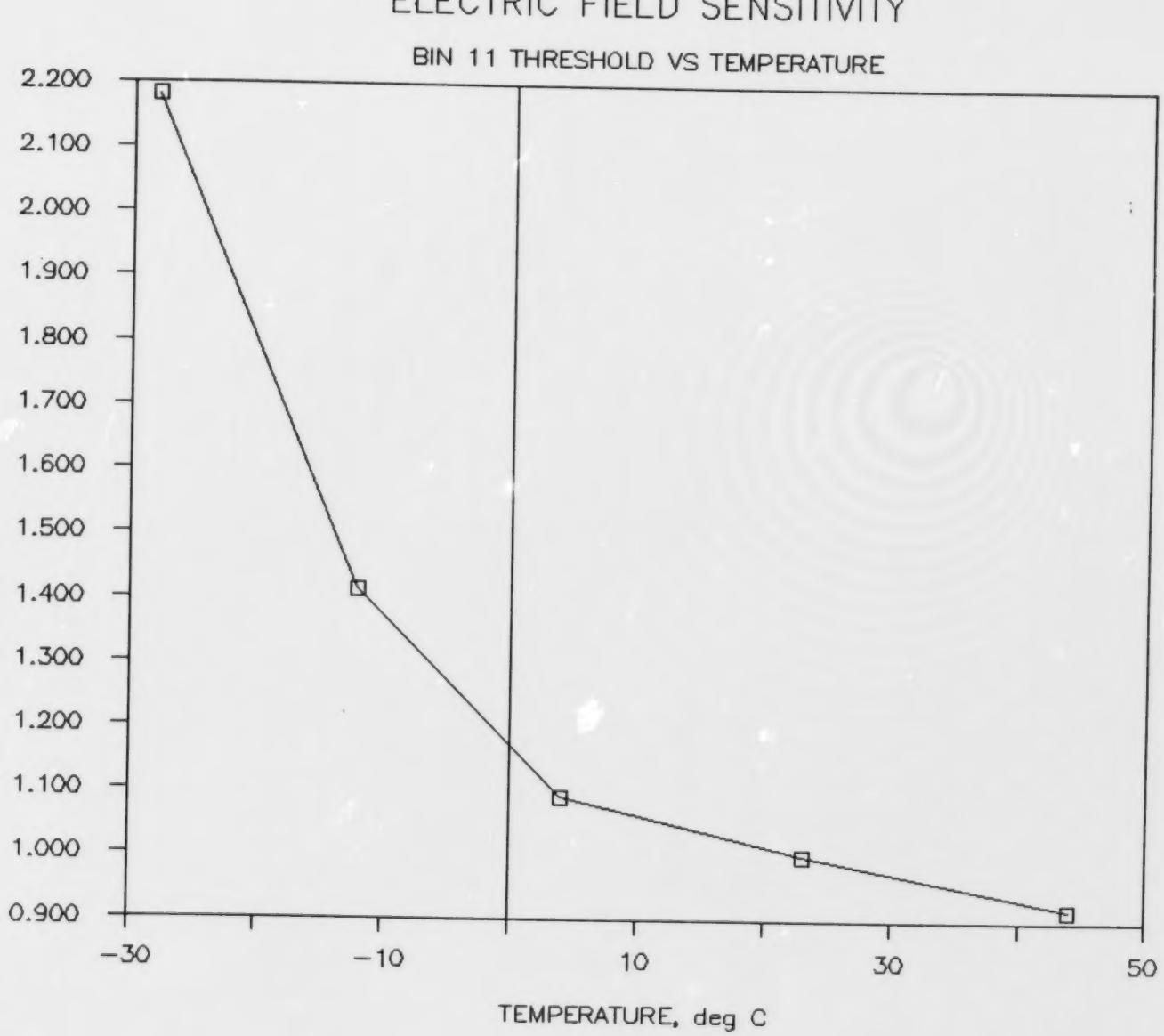

ELECTRIC FIELD SENSITIVITY
BIN 11 THRESHOLD VS TEMPERATURE
NORMALIZED ELECTRIC FIELD (23 C)
2.200
2.100
2.000
1.900
1.800
1.700
1.600
1.500
1.400
1.300
1.200
1.100
1.000
0.900
-30
-10
10
30
50
TEMPERATURE, deg C

FIGURE 11

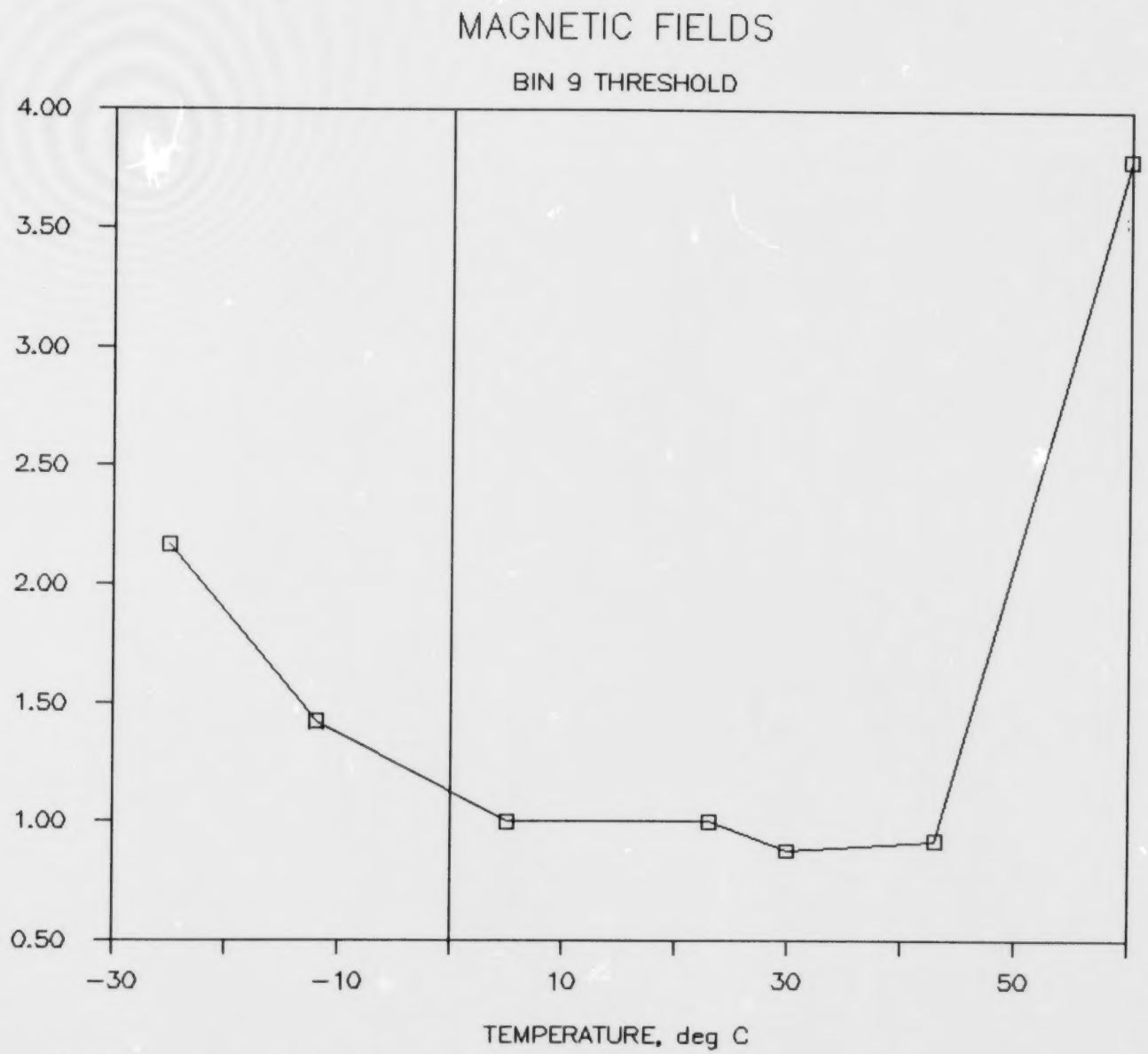
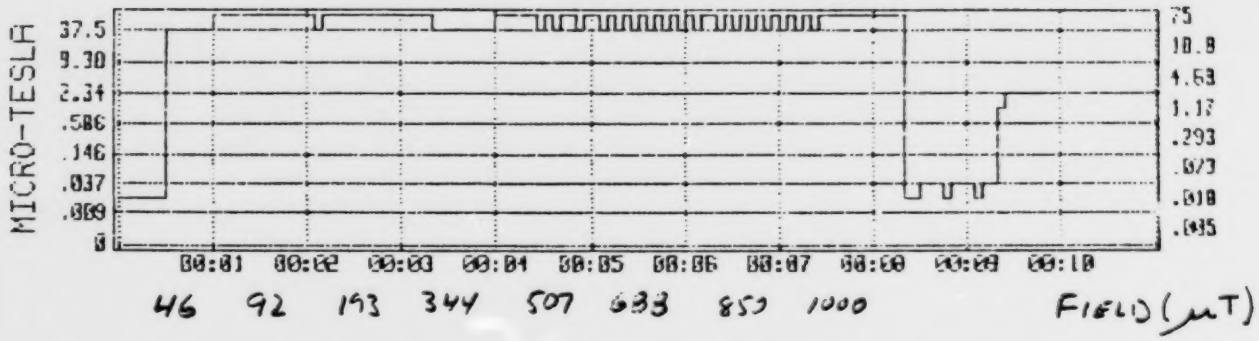

MAGNETIC FIELDS
BIN 9 THRESHOLD
NORMALIZED MAGNETIC FIELD (23 C)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
-30
-10
10
30
50
TEMPERATURE, deg C

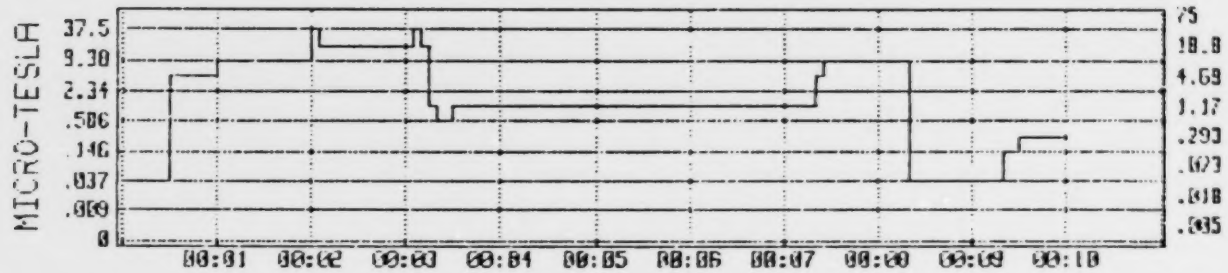
FIGURE 12

User : MAGNETOVERLOADTEST3 File : SCR5 START: 25 JAN 1988 , 00:00
Ser.Number : Period : 5 sec. Enh. Factor : 1

MAGNETIC FIELD (X)



MAGNETIC FIELD (Y)



MAGNETIC FIELD (Z)

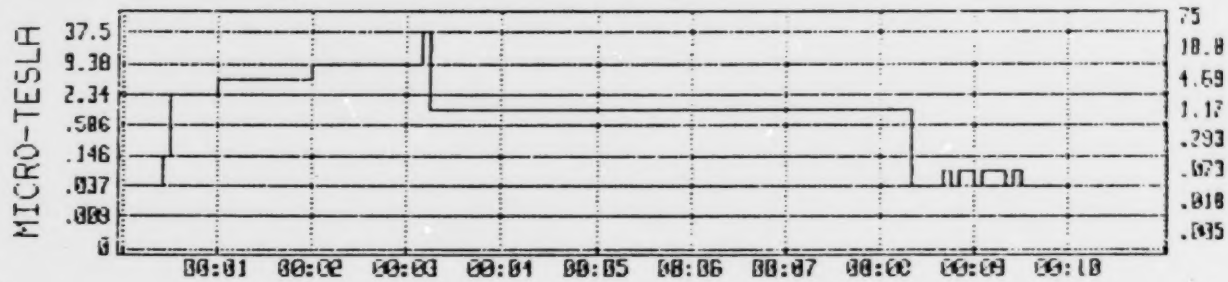


FIGURE 13

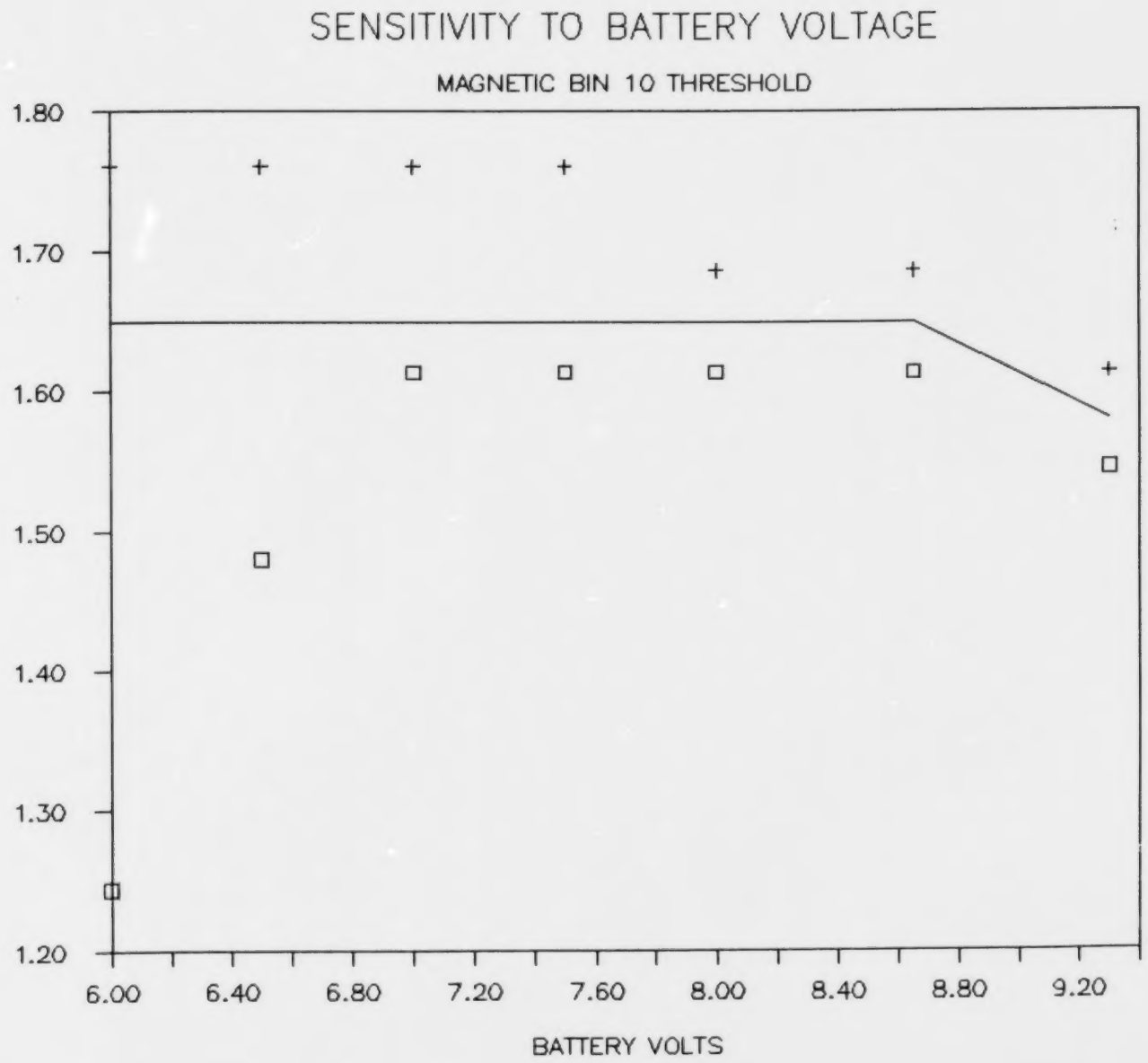

SENSITIVITY TO BATTERY VOLTAGE
MAGNETIC BIN 10 THRESHOLD
1.80
1.70
1.60
1.50
1.40
1.30
1.20
THRESHOLD, uT
6.00
6.40
6.80
7.20
7.60
8.00
8.40
8.80
9.20
BATTERY VOLTS

FIGURE 14